JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

DESIGN AND STATIC STRUCTURAL ANALYSIS OF COMPOSITE LEAF SPRING FOR AUTOMOTIVE VEHICLE

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ABSTRACT

In now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfil this problem the automobile industries are trying to make new vehicle which can provide high efficiency with low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. To reduce vehicle weight, three techniques have been studied rationalizing the body structure, utilizing lightweight materials for parts and decreasing the size of the vehicles. In this approach by introducing composite materials into automobile industries, which is having low cost, high strength to weight ratio and excellent corrosive resistance can fulfil the requirement.

The automobile vehicles have number of parts which can be able to replace by composite material, but due to the improvement of mechanical properties of composite material. It has more elastic strength and high strength to weight ratio has compared with those of steel material. So, out of many components one of the components of automobile, the leaf spring which use for carried out the whole weight of the vehicle is best option for replacement of steel material by composite materials. Leaf springs are used in suspension systems. The automobile industry has shown increased interest in the replacement of steel leaf spring with composite leaf spring due to high strength to weight ratio.

Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe design and analysis of composite leaf spring. For this purpose, a rear leaf spring for Mahindra Thar D117 CRDe Diesel leaf spring is considered.

In this project we demonstrate the design and analysis of a Mahindra Thar D117 CRDe Diesel leaf spring is considered which is made up of coir reinforced polyester matrix composite and fibre reinforced polymer (S-glass/epoxy). The main objective of this project is to reduce the weight of an automobile by replacing its steel leaf spring with composite leaf spring when the load applied is constant and at the same defection compare its relative merits and demerits. The modelling of leaf-springs is done using NX -10.0 and analysis is done using ANSYS 18.1.

Keywords: Stiffness, Composite Leaf Spring, E-Glass/Epoxy, ANSYS 12.0, NX10.0 – CAD

1. INTRODUCTION

In order to conserve natural resources and economize energy, weight reduction has become the main focus of automobile manufacturers and the Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles. A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. The spring consists of a number of leaves called blades. The blades are varying in different lengths. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength.

Fig 1. Leaf Springs

Fig 2. A traditional leaf spring arrangement.

The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leaves.All the blades are bound together by means of steel straps.Semi- elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. This achieves the vehicle more fuel efficiency and improved riding qualities.The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential Energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies a material made with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. The leaf springs are more affected due to fatigue loads, as they are a part of the unsprung mass of the automobile. In the present work, a normal leaf steel spring used in passenger cars or light duty vehicles is replaced with a composite multi leaf spring made of coir reinforced polyester matrix composite and fibre reinforced polymer (S-glass/epoxy). The dimensions and the number of leaves for both steel leaf spring and composite leaf springs are different. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction in the load-carrying capacity and stiffness.

2. LITERATURE REVIEW

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing [1].

The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device [2].

According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring [3].

To meet the need of natural resources conservation, automobile manufacturers are attempting to reduce the weight of vehicles in recent years [4].

Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness[5].

For weight reduction in automobiles as it leads to the reduction of un-sprung weight of automobile. The elements whose weight is not transmitted to the suspension spring are called the un-sprung elements of the automobile. This includes wheel assembly, axles, and part of the weight of suspension spring and shock absorbers. The leaf spring accounts for 10-20% 0f the un-sprung weight [6].

The composite materials made it possible to reduce the weight of machine element without any reduction of the load carrying capacity. Because of composite material's high elastic strain energy storage capacity and high strength-to-weight ratio compared with those of steel [7],[8].

3. MATERIALS

The material used for leaf springs is usually a plain carbon steel having 0.90 to1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

According to Indian standards, the recommended materials are :

1.For automobiles : 50 Cr 1, 50 Cr 1 V 23, and 55 Si 2 Mn 90 all used in hardened and tempered state.

2. For rail road springs: C 55 (water-hardened), C 75 (oil-hardened), 40 Si 2 Mn 90(water hardened) and 55 Si 2 Mn 90 (oil-hardened).

3. The physical properties of some of these materials are given in the following table. All values are for oil quenched condition and for single heat only.

Physical properties of materials commonly used for leaf springs

3.1. STEEL

Steel is an alloy of iron that contains the element iron as the major component and small amounts of carbon as the major alloying element. The carbon contents in steel ranges from 0.02% to 2.0% by weight. Small amounts, generally on the order of few percent, of other alloying elements such as manganese, silicon, chromium, nickel and molybdenum may also be present, but it is the carbon content that turns iron into steel. Also the properties like toughness and ductility are obtained by the addition of elements like manganese, chromium, nickel, molybdenum, tungsten, vanadium, silicon etc. Steel is the most common and widely used metallic material in today's society. It can be cast or wrought into numerous forms and can be produced with tensile strength exceeding 5GPa.

Table 1 Mechanical Properties of Steel

Property	Value
Density	7850kg/m2
Tensile Yield Strength	250 MPa
Poisson's ratio	0.3
Young's modulus	210 Gpa

3.2. Coir Fibre And Glass Fibre

In our project work we can go through One of the natural fibers which is available in abundant in nature and also very cheap, Coir, is used as the reinforcement for polyester in this composite. Coir is a fiber, obtained from various parts of coconut tree like coconuts and at leaves. It is well treated with salt water and rinsed with chemicals to make it dust free. It is then cut in to required size. Composite

properties are taken from the journal published by P N E Naveen and M Yasasvi [9].

Figure 1. Coir fibre.

Figure 2. glass fibre

Table 2 Properties of Coir composite

Property	Value
Density	1380 kg/m^3
Tensile Yield Strength	25 MPa.
Poisson's ratio	0.3
Young's modulus	315Gpa

Table 3 Properties of S-glass/Epoxy composite

Property	Value
Density	2480 kg/m^3
Tensile Yield Strength	4585 MPa.
Poisson's ratio	0.22
Young's modulus	86900Mpa

4. **DESIGN OF LEAF SPRING**

4.1. Model-Mahindra "Mahindra Thar D117 CRDe Diesel"

Leaf springs (also known as flat springs) are made out of flat plates. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque; driving torque etc., in addition to shocks.

Let

t = Thickness of plate,

b= Width of plate,

2 L= Effective length of leaf spring

l = ineffective length of leaf spring

N_f = Number of full-length leaves

N_g = Number of graduated leaves

n = Total number of leaves = $N_{f} + N_g$

2W = Central load acting

FOS = factor of safety

$\delta_{f} =$ Defection in full length leave

For reference and comparison sake a general leaf-spring of Model-Mahindra "Mahindra Thar D117 CRDe Diesel" was considered. The Dimensions of leaf spring as determined as follows

Number of leaf springs = 10

Effective length of leaf spring = 1120 mm

Width of leaves = 50mm

Number of full-length leaves = 2

Number of graduated leaves = 8

Total number of leaves = 10

Central load acting = 2W=1910Kg

2W=1910X10X1.33(FOS)

= 25403 N

2W = 25403/4

= 6350.7

W = 3200 N

4.1.1 Material used for leaf spring: structural steel

Bending stress = $\frac{6WL}{nbt2}$

$= \frac{6X1600X560}{10X50X6\ 2}$

= 299 N/mm^2

Deflection in full length leaves = $\frac{12WL3}{E\ b\ t\ 3\ (2\ n\ G+3\ n\ F)}$

= (12X1600X560$^{3)}$ /(207X(10)^{3}X50X6^3(2X8+3X2))

= 68.5 mm.

Length of leaf = $\frac{effectivelength}{number\ of\ leaves-1} + ineffctive\ length$

Length of smallest leaf (leaf 1) = $\frac{1120}{10-1} + \mathbf{90}$ = 214 mm

Length of second leaf = $\frac{1120}{10-1} X2 + 90 = 338\ mm$

Length of third leaf = $\frac{1120}{10-1} X3 + 90 = 463\ mm$

Length of fourth leaf = $\frac{1120}{10-1} X4 + 90 = 588\ mm$

Length of fifth leaf = $\frac{1120}{10-1} X5 + 90 = 712\ mm$

Length of sixth leaf = $\frac{1120}{10-1} X6 + 90 = 837\ mm$

Length of seventh leaf = $\frac{1120}{10-1} X7 + 90 = 961\ mm$

Length of eight leaf = $\frac{1120}{10-1} X8 + 90 = 1085\ mm$

Length of nineth leaf = 1120 mm

Length of tenth leaf = 1120 mm

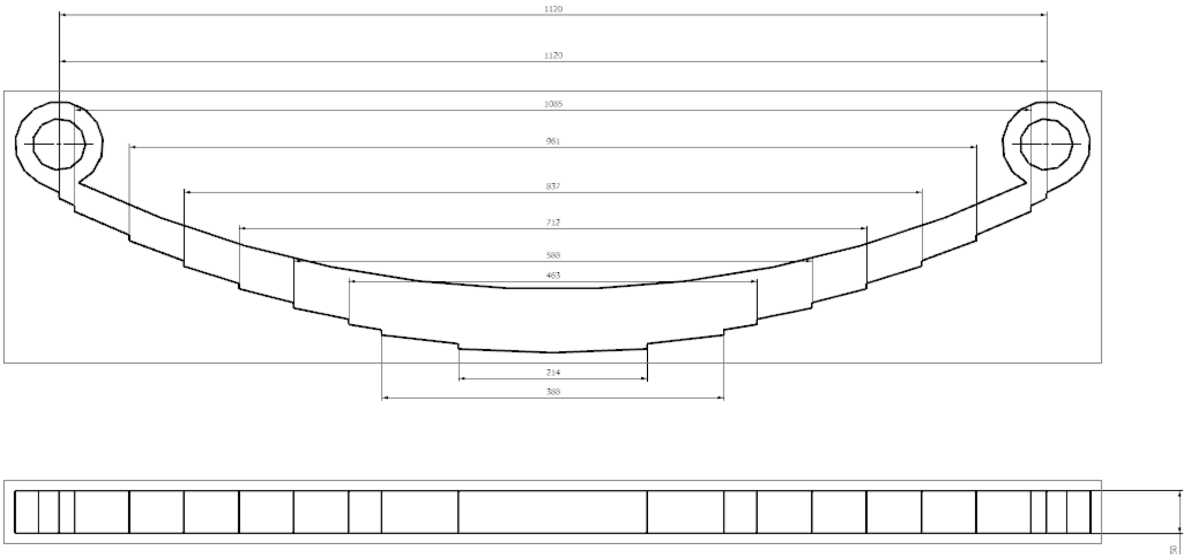

Fig:3 Drafting of steel leaf spring

4.1.2 Dimensions of Coconut Fibre Reinforced Polyester Composite Leaf-Spring and Fiber reinforced polymer (S-glass/epoxy)

The dimensions of composite leaf springs are set in such a way that, when 3200 N is applied, the deflection should be same as that of steel leaf-spring.

Deflection in full length leaves $= \frac{12WL3}{E\,b\,t\,3\,(2\,n\,G+3\,n\,F)}$

$68.5 = (12X1600X560^3)\,/(207X(10)^3XbX8^3(2X8+3X2))$

b = 67 mm

Firstly, length of 1420 mm and thickness of 8 mm is fixed and width is calculated using above formula.

Length of leaf = $\frac{effectivelength}{number\ of\ leaves-1} + ineffctive\ length$

Length of smallest leaf (leaf 1) = $\frac{1420}{10-1} + 90$ = 247.7 mm

Length of second leaf = $\frac{1420}{10-1}X2 + 90 = 405.55\ mm$

Length of third leaf = $\frac{1420}{10-1}X3 + 90 = 563.33\ mm$

Length of fourth leaf = $\frac{1420}{10-1}X4 + 90 = 721.11\ mm$

Length of fifth leaf = $\frac{1420}{10-1}X5 + 90 = 878.88\ mm$

Length of sixth leaf = $\frac{1420}{10-1}X6 + 90 = 1036.66\ mm$

Length of seventh leaf = $\frac{1420}{10-1}X7 + 90 = 1194.4\ mm$

Length of eigth leaf = $\frac{1420}{10-1}X8 + 90 = 1352.22\ mm$

Length of nineth leaf = 1420 mm

Length of tenth leaf = 1420 mm

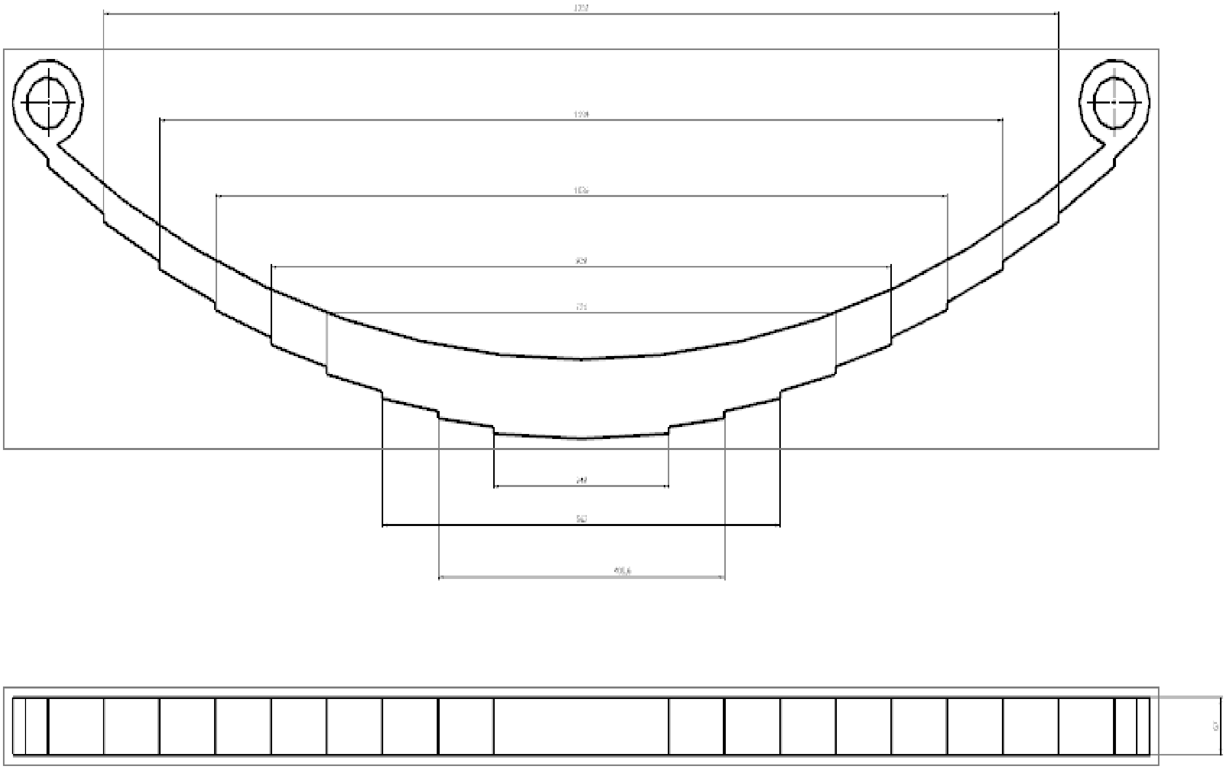

Fig:4 Drafting of coconut fibre composite leaf spring

4.2 MODELING OF THE STEEL LEAF SPRING:

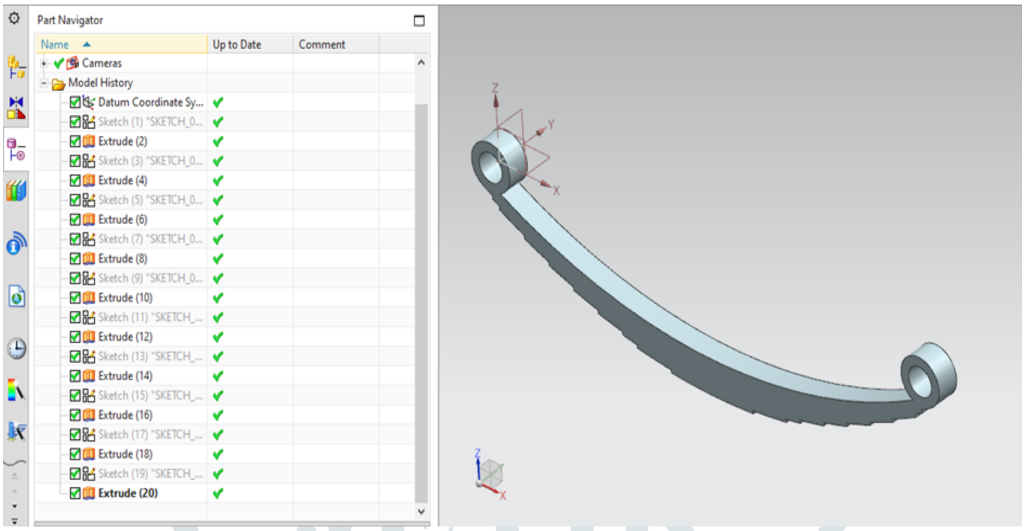

Fig.5 Modelling of Steel Leaf Spring

4.3 MODELING OF THE COCONUT FIBRE COMPOSITE LEAF SPRING:

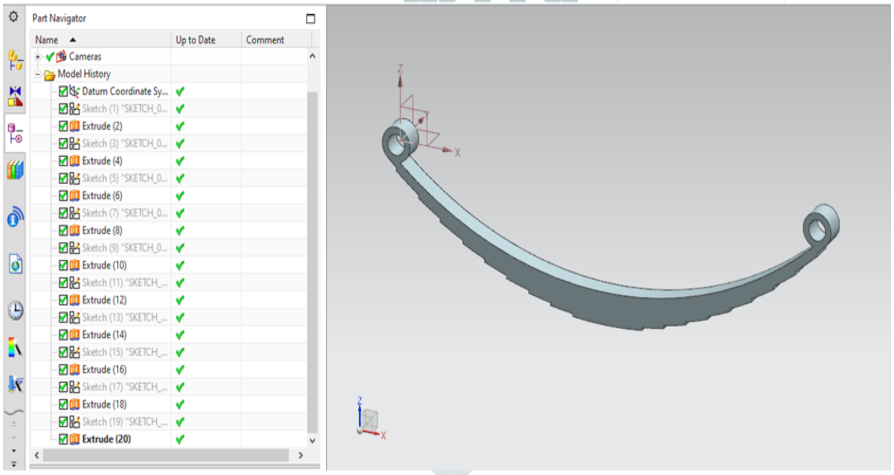

Fig: 7 Modeling of coconut fiber composite leaf spring

4.4 MODELING OF THE S-GLASS /EPOXY COMPOSITE LEAF SPRING:

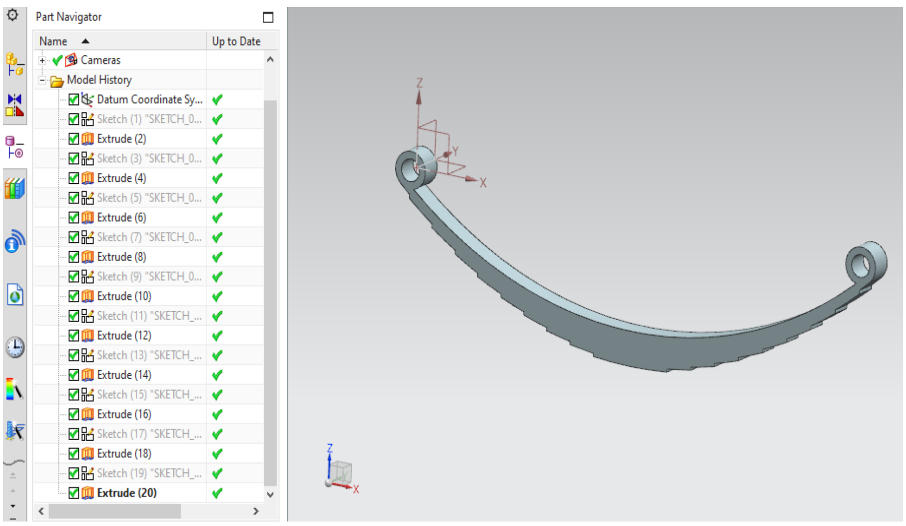

Fig: 9 Modeling of S-glass/epoxy composite leaf spring

5. ANALYSIS

INTRODUCTION TO ANSYS

Today computer technology helps solving most complex problems. It is effectively used not only for structural analysis but also for a wide range of phenomenon such as static (structural, creep, fatigue, fracture), dynamic (linear and non-linear), vibration and noise, heat transfer, fluid flow; in addition to manufacturing processes such as injection molding and metal forming..

As CAD/CAM/CAE technology is much advanced, ANSYS, evolved as the most popular and complete CAE package with its highly powerful capabilities to help us understand the real world functionality of a design.

FINITE ELEMENT METHOD

The finite element method is a numerical method that involve complicated physics, geometry, boundary conditions. In finite element method, a given domain is viewed as a collection of sub domains and over each sub domain the governing equation is approximated by any of the traditional vibration methods.

5.1 PROCEDURE:

5.1.1 Importing the Model:

In this step the UG-NX model is to be imported into ANSYS workbench as follows:

In utility menu file option and selecting import external geometry and open file and click on generate. To enter into simulation module click on project tab and click on new simulation

5.1.2 Defining Material Properties:

To define material properties for the analysis, following steps are used

The main menu is chosen select model and click on corresponding bodies in tree and then create new material enter the values again select simulation tab and select material

5.1.3 Defining Element Type:

To define type of element for the analysis, these steps are to be followed:

Chose the main menu select type of contacts and then click on mesh-right click-insert method

Method - Tetrahedrons

Algorithm - Patch Conforming

Element Mid side Nodes – Kept

5.1.4 Meshing the model:

To perform the meshing of the model these steps are to be followed:

Chose the main menu click on mesh- right click- insert sizing and then select geometry enter element size and click on edge behavior curvy proximity refinement and then right click generate mesh .

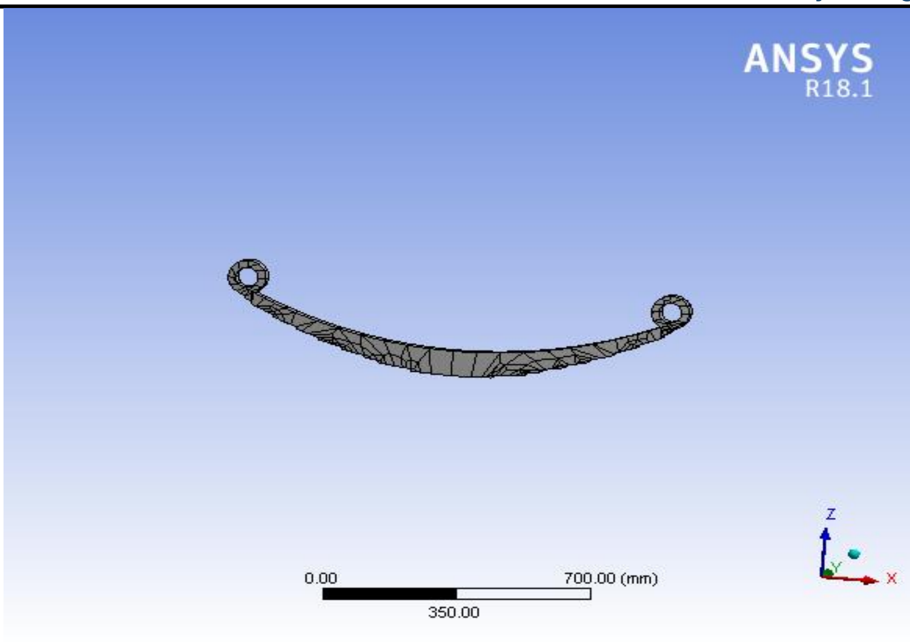

Fig 11: Mesh generation for steel leaf spring

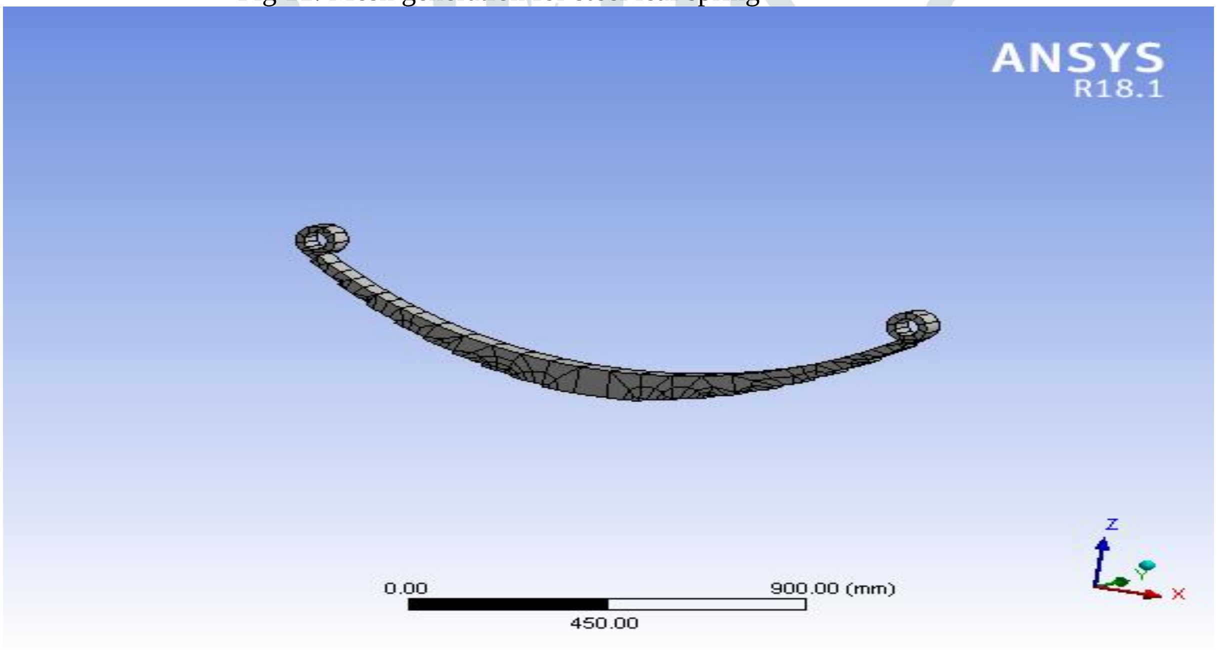

Fig 12 : Mesh generation for coconut fiber composite leaf spring

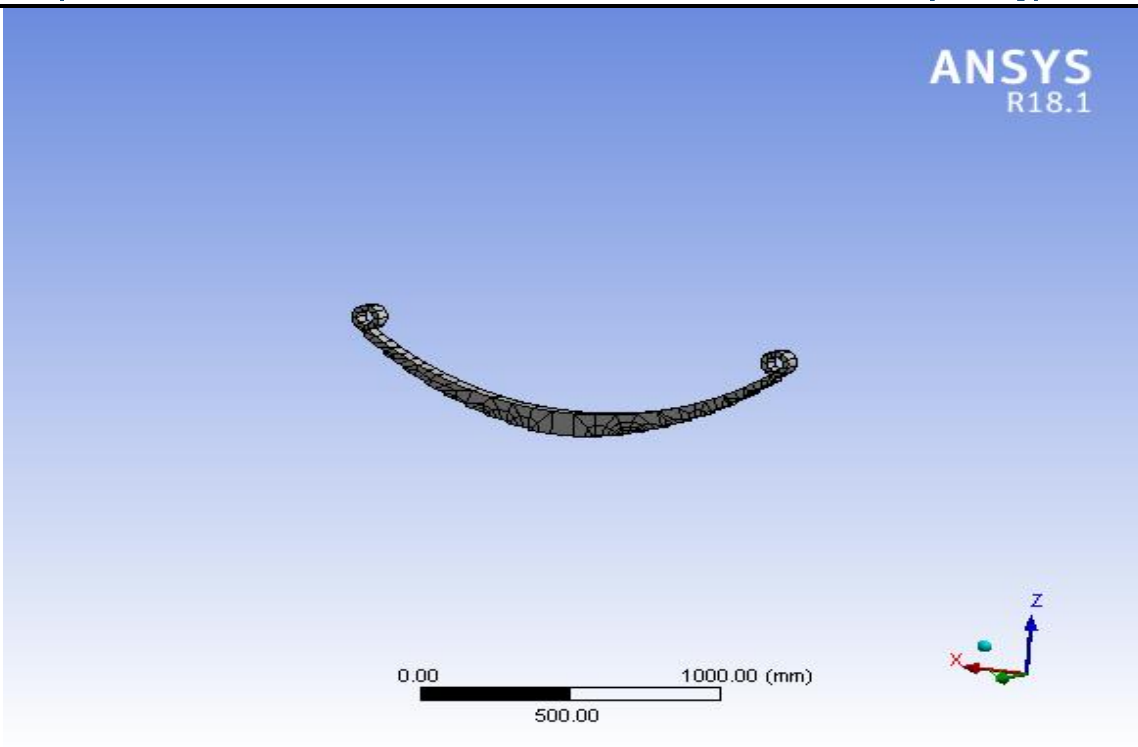

Fig 13 : Mesh generation for S glass/Epoxy composite leaf spring

6. RESULT

6.1 Analysis of steel Leaf Spring

The steel leaf-spring is analysed by giving constraints and the results obtained are as follows.

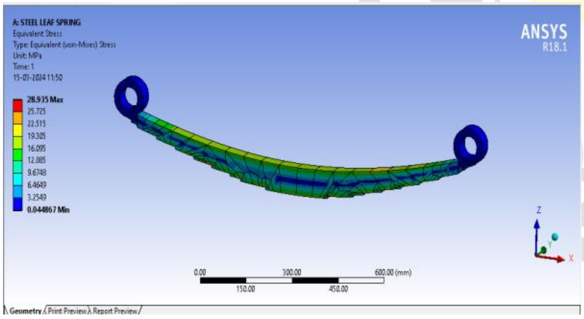

Fig.14 .Max. Stress distribution.

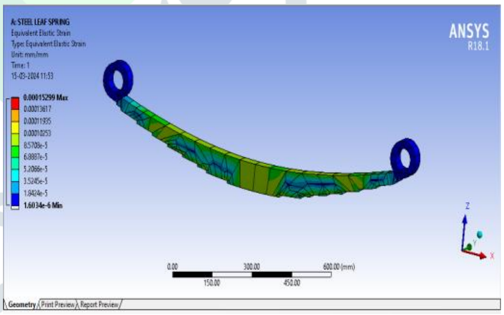

Fig.16 .Max. strain distribution

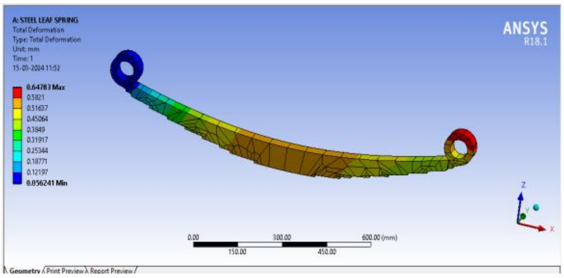

Fig.15. .Max. Deformation

6.2 Analysis of coconut fibre composite Leaf Spring

The coconut fibre composite leaf-spring is analysed by giving constraints and the results obtained are as follows.

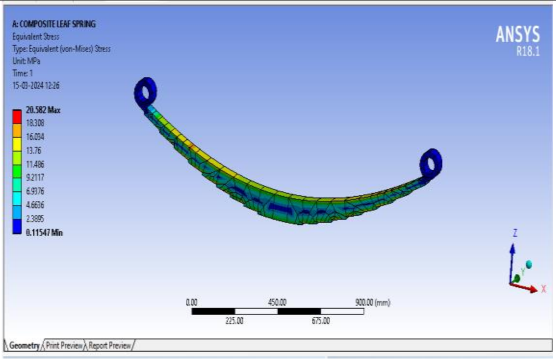

Fig.17.Max. Stress distribution

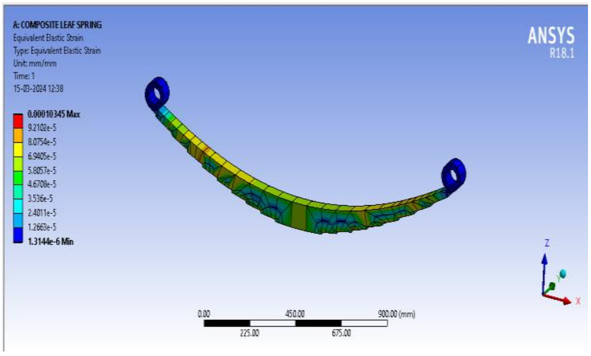

Fig.19 .Max. strain distribution

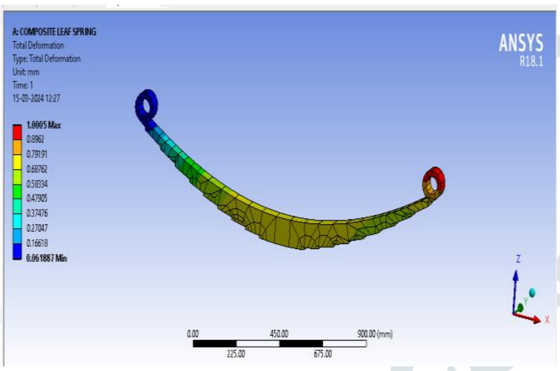

Fig.18.Max. Deformation

6.3 Analysis of S GLASS/EPOXY composite Leaf Spring

The S Glass/Epoxy composite leaf-spring is analysed by giving constraints and the results obtained are as follows.

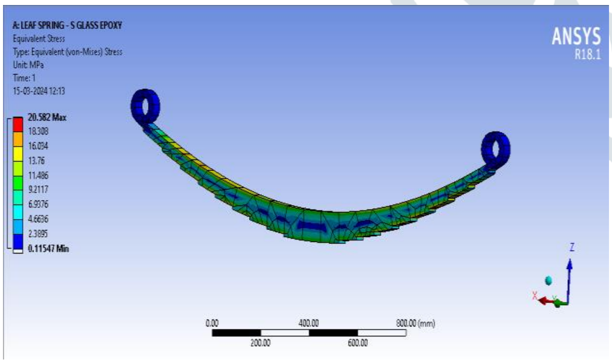

Fig.20.Max. Stress distribution

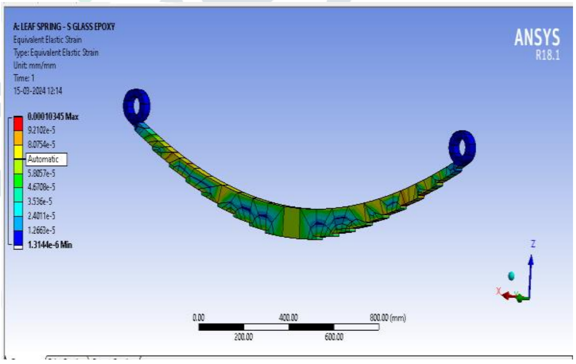

Fig.22.Max. strain distribution

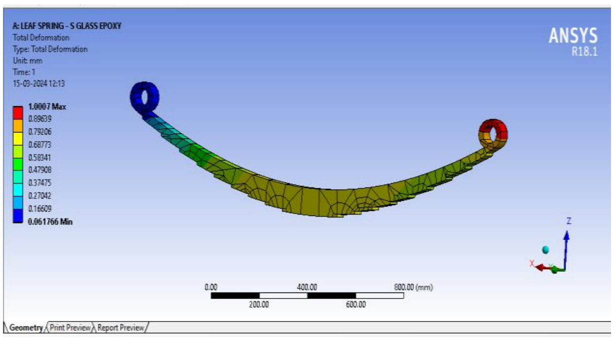

Fig.21.Max. Deformation

Table 4. Comparison of Analysis Results of steel leaf and composite leaf springs

S. No	Material for leaf spring	Max stress (Mpa)	Max Deformation(mm)	Max. strain distribution	Weight (Kg)
1	Steel leaf spring	28.935	0.64783	0.00015299	**28.2727**
2	S Glass/Epoxy composite leaf spring	20.582	1.0007	0.00010345	**17.9988**
3	Coconut fiber Composite leaf spring	20.582	1.0005	0.00010345	**10.0155**

Percentage of Weight saved (coconut fiber composite leaf spring)

$$= \frac{(28.2727-10.0155)}{28.2727}$$

= 64.575%

Percentage of Weight saved (S Glass/Epoxy composite leaf spring)

$$= \frac{(28.2727-17.9988)}{28.2727}$$

= 36.338%

From the results it can be observed that Equivalent stress generated in the Coconut Fiber Reinforced Polyester Composite leaf spring is less compared to S Glass/Epoxy composite leaf spring and steel leaf spring. Less maximum strain and acceptable deformation have been found in Coconut Fiber Reinforced Polyester Composite leaf spring compared to S Glass/Epoxy composite leaf spring and conventional steel leaf spring.

7. CONCLUSIONS

Under the same static load and deflection conditions, both composite and steel leaf springs show great difference in their weights. The weight of steel leaf spring is very high compared to that of composite leaf springs. The weight of steel spring is 28.2727 kgs whereas weight of S Glass/Epoxy composite leaf spring is 17.9988Kg and weight of coconut fibre composite leaf spring is 10.0155 kgs. The induced stress of coconut fibre composite leaf spring is 20.582 MPa which is equal to the S Glass/Epoxy composite leaf spring less than that of steel leaf spring 28.935 MPa. The results obtained for deflection of steel leaf spring and composite leaf springs are in acceptable range. Composite leaf spring can be used in light weight vehicles, where weight is an important factor, whereas steel spring can be used in budget cars for its low cost of manufacturing.

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